SYNTHESIS, CHARACTERIZATION AND APPLICATIONS OF DIVALENT METAL IONS DOPED NICKEL FERRITES

SYNOPSIS

Submitted in partial fulfilment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY
in
Chemistry

Submitted by

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2020-2021

1. Introduction

Nanoscience and nanotechnology are the study and applications of extremely small things that can be used across all the other sciences. Nanotechnology mainly deals with nanodevices and nanomaterials. Nanomaterials mean those substances whose dimensions lies in nanoscale i.e. in the range of 1 nm to 100 nm. Physicist Feynmann is the father of nanotechnology. In December, 1959 he started with a talk entitled, "There is a plenty of room at the bottom" at An American Physical society meeting at the California Institute of Technology. He described it as a process in which scientist would manipulate the size as well as properties of smallest particles i.e. atoms and molecules. The particles generated at the nanoscale have unique electrical, optical and magnetic properties. This is because of their large surface area, quantum confinement and high surface energy (Salata, 2004). Magnetic nanoparticles are those particles which can be easily tracked, manipulated and targeted using external magnetic field. Finite size and surface effects of these particles increase their utility (Lu, Salabas & Schuth, 2007). There are so many applications of magnetic nanoparticle in biomedical, biotechnology, engineering, material science and environmental areas (Faraji et al., 2010).

Magnetic materials mainly consist of transition metals, inner transition metals and their oxides. Electrons present in the outer most shell of these elements determine the magnetic properties. Spinning motion of these electrons around the nucleus and its axis leads to the generation of orbital and spin magnetic moment. The observed magnetic moment is the sum of orbital and spin magnetic moment (Jauhar, 2014). Based upon the alignment of magnetic moment, the materials are classified as paramagnetic, diamagnetic, ferromagnetic, ferrimagnetic and antiferrimagnetic (Mohammed et al., 2017). Ferrites are generally ferrimagnetic ceramic compounds procured from iron oxide (Hussein & Katayama-Yoshida, 2019).

Ferrites are very important magnetic nanoparticles due to their vide applications in the field of biomedical sciences, electronics, magnetic field assisted radioactive chemical separation (Bahadur et al., 2005). Ferrites are classified as soft and hard ferrites on the basis of their magnetic properties (Kumari et al., 2020). Ferrites with low coercive forces are termed as soft ferrites while ferrites with high coercive forces are called as hard ferrites (Rani, Radhika & Padma, 2020). Based upon the structure, ferrites can be categorised as spinel, hexagonal, garnets and ortho ferrites (Tolani, Golhar & Rewatkar, 2019). Low eddy current losses and high electrical resistivity make the spinel ferrites

highly useful in the field of electronics and communications, computer memory chips, magnetic refrigerators, switching devices, transformer core sensor technology (Gul & Akhtar, 2018).

Spinel ferrites have general formula AB_2O_4, where A and B are cations, The crystallographic unit cell of ferrite contains eight formula units of AB_2O_4, resulting in 64 tetrahedral sites (8 occupied) and 32 octahedral sites (16 occupied) (Mello et al., 2019). Based upon the distribution of divalent metal ions and Fe^{+3} in the two cationic sites, spinel ferrites are classified as normal, inverse and mixed spinels (Narang & Pubby, 2021).

Nickel Ferrites

Spinel ferrites with nickel as divalent cation are referred as nickel ferrites. Nickel ferrite possesses inverse spinel structure in which 8 tetrahedral sites (A-site) are occupied by Fe^{+3} ions and 16 octahedral sites (B-site) are occupied by Fe^{+3} and Ni^{+2} ions in equal proportion. High electrical resistivity, low coercivity, low hysteresis losses and moderate saturation magnetisation categorises the nickel ferrites as soft ferrites (Pardavi-Horvath, 2000). Nickel ferrites have so many applications likewise as a effective sensor for industrial and environmental pollutant detection (Koli, Kapadnis & Deshpande, 2019), photo catalytic degradation of dyes (Vijay et al., 2019), removal of heavy metals (khoso et al., 2021), biomedical field (Rodrigues et al., 2015) etc. The properties of ferrites nanoparticles are highly dependent on size, morphology and composition which are connected with synthesis process and preparation conditions (Pande et al., 2019).

Nanoparticles synthesis can be achieved by two distinct pathways: a top-down and bottom-up approach (Arole & Munde, 2014). In top down approach macro particles get converted to nano size particles, while in bottom-up micro size particles get converted to nano size particles. In Bottom-up approach the magnetic nanoparticles can be synthesized by physical, chemical and biological routes (Hussain et al., 2016). There are so many chemical routes to synthesize ferrite nanoparticles like co-precipitation, ball milling, sol-gel, hydrothermal and combustion method (Vinosha et al., 2018). Among all these methods, synthesis by co-precipitation is preferred due to its simplicity, high mass production, cost effectiveness, homogeneity, less time consuming, better control over morphology, crystallite size etc. (Moussaoui et al., 2016).

The substitution of divalent ions in pure ferrites leads to the modification of the structural, electrical, optical and magnetic properties (Zhong et al., 2005). These

properties can be tailored by the choice of magnetic nanoparticles synthesis route, composition of chemicals, nature of dopant ions and thermal conditions (Cadar et al., 2020).

2. Literature Review

Aliahmad et al., (2013) synthesised nickel ferrite nanoparticles by chemical co-precipitation method using $FeCl_3.6H_2O$ and $NiCl_2.6H_2O$ as starting material. They used oleic acid as a capping agent and NaOH as a precipitating agent to get the pH value of 13. They heated the contents at 80ºC for 40 minutes. After that the synthesised product is washed, dried at 80ºC and calcinated in the range of 500-1000ºC. The synthesized nanoparticles have crystalline size of 7-82 nm. XRD, FTIR, VSM, TEM, SEM and EDX techniques were used to characterize the nanoparticles.

Moradmard et al., (2017) synthesised magnesium doped nickel ferrite nanoparticles with formula $Ni_{1-x}Mg_xFe_2O_4$ (x = 0.0, 0.1, 0.3, 0.5, 0.7) by co-precipitation method. During the synthesis process starting materials were salts of $FeCl_3.6H_2O$, $NiCl_2.6H_2O$ and $MgCl_2.6H_2O$. The pH of the solution was adjusted to 13 by adding NaOH solution. The reaction was carried out at 85ºC for 2hours. The synthesised product was washed, dried at 70ºC for 24 h and then annealed at 900ºC. XRD, FESEM, FTIR, EDX, and VSM techniques were used to characterize the nanoparticles. The crystalline size varied from 30-38 nm with increase of Mg content in nickel ferrite.

Toqeer et al., (2019) synthesized copper doped nickel ferrite with formula $Ni_{1-x}Cu_xFe_2O_4$ ($0 \leq x \leq 3$) by co-precipitation method. $FeCl_3.6H_2O$, $NiCl_2.6H_2O$ and $CuCl_2.2H_2O$ were used as starting materials and NaOH as precipitating agent to adjust the pH of the solution to 12. Components were mixed together by continuous stirring. After washing and drying at 70ºC for 4h, the synthesized sample was annealed at 700ºC for 4h. XRD, SEM, VSM and FTIR techniques were used to characterize the nanoparticles. They found that as the copper content increased in the sample, the value of coercivity and remnant magnetisation were decreased.

Kumari et al., (2020) synthesised cobalt substituted nickel ferrite with formula $Ni_{1-x}Co_xFe_2O_4$ (x = 0, 0.25, 0.5, 0.75, 1.0) by co-precipitation method.$FeCl_3.6H_2O$, $NiCl_2.6H_2O$ and $CoCl_2.6H_2O$ as a starting material and NaOH as precipitating agent to adjust the pH of solution to 10. The components were heated at constant temperature of 60ºC. Synthesized product was washed, dried at 200ºC for 3h and then calcinated at 800ºC for 4h. Nanoparticles have crystalline size in the range of 23-66 nm. XRD, FTIR,

EDS, SEM and UV-Vis. Spectroscopy techniques were used to characterize the nanoparticles.

Mirzaee et al., (2020) synthesized manganese doped nickel ferrites with three different conc. of manganese 0.1 M, 0.25 M, 0.5 M by co-precipitation method. $FeCl_3.6H_2O$ and $NiCl_2.6H_2O$ were taken as starting material. NaOH as precipitating agent and Mn^{+2} ions added after the formation of nucleation centres in the reaction medium. After washing, drying at 50^{o}C the sample was annealed at 500^{o}C for 2h. XRD, FTIR, FESEM-EDX and VSM techniques were used to characterize the synthesized nanoparticles.

Vinosha et al., (2018) synthesized zinc substituted nickel ferrites with formula $Ni_{1-x}Co_xFe_2O_4$ (x = 0.01, 0.03, 0.05, 0.1) by co-precipitation method. Salts of Fe $(NO_3)_3$, Ni $(NO_3)_2$and Co $(NO_3)_2$ were taken as starting materials and NaOH solution added to adjust the pH of the solution to 8. The contents were heated at 80^{o}C for 2h with constant stirring. The obtained product was washed, dried at70^{o}C for 2h and then calcinated at 500^{o}C for 3h. The crystalline size was found to be varying from 8-15nm. XRD, FTIR, FT-Raman, TEM, BET, UV-Vis. And VSM techniques were used to characterize the synthesized nanoparticles.

Thakur et al., (2016) synthesized Ni-Zn ferrites of composition $Ni_{0.5}Zn_{0.5}Fe_2O_4$ by co-precipitation method. $FeCl_3.6H_2O$, $NiCl_2.6H_2O$ and $ZnCl_2$ were used as starting materials and NaOH as a precipitating agent. The sample was heated, washed, dried at 80^{o}C and annealed at 800^{o}C and 900^{o}C for 3h. XRD, FTIR, FESEM and VSM techniques were used to characterize the nanoparticles. They found that in synthesized nanoparticles saturation magnetisation increased while coercivity values decreased with increase in sintering temperature.

Sendhilnathan et al., (2017) synthesized Mg^{+2} substituted nickel ferrites with formula $Ni_{1-x}Mg_xFe_2O_4$ (x = 0.2, 0.4, 0.6, 0.8, 1.0) by simple co-precipitation method. $FeCl_3.6H_2O$, $NiCl_2.6H_2O$ and $MgCl_2.6H_2O$ were taken as staring material. These solutions were poured into boiling NaOH solution. The contents were heated at 100^{o}C with constant stirring for 1h. The obtained precipitate washed, dried at 110^{o}C and calcinated at 550^{o}C. The crystalline size of nanoparticles decreased from 28-10nm, coercivity and remenant decreased as well as saturation magnetisation increased with increase in Mg content. XRD, FTIR, SEM, TEM and VSM techniques were used to characterize the nanoparticles.

Ajeesha et al., (2021) synthesized nickel substituted magnesium spinel ferrite nanoparticles with formula $Mg_{1-x}Ni_xFe_2O_4$ (x = 0.0, 0.6, 1.0) by chemical co-precipitation method. $Mg(NO_3)_2$, $Ni(NO_3)_2.6H_2O$ and $Fe(NO_3)_3.9H_2O$ were taken as starting materials. NaOH solution was added to adjust the pH of the solution 13. The resulting solution was heated at 80°C for 3h. Synthesized product was washed, dried at 75°C for 24h and calcinated at 650°C for 8h. The average crystalline size of nanoparticles was found to be in the range of 20-30nm. XRD, FTIR, HRTEM, BET, UV-Vis and VSM techniques were used to characterize the nanoparticles.

Lassoued et al., (2017) synthesized copper substituted nickel ferrite with formula $Cu_{1-x}Ni_xFe_2O_4$ (x = 0.0, 0.2, 0.5, 0.8, 1.0) by chemical co-precipitation method. $FeCl_3.6H_2O$, $NiCl_2.6H_2O$ and $CuCl_2.2H_2O$ were used as starting materials. These contents were kept at 80°C and added to the boiling solution of NaOH and then added few drops of oleic acid which act as surfactant and coating material. The obtained product was washed, dried at 80°C for 3h and calcinated at 900°C for 6h. The crystalline size was found in the range of 14-43nm. XRD, FTIR, SEM, TEM, UV-Vis, TGA-DTA and VSM techniques were used to characterize the nanoparticles.

Vigneswari & Raji (2017) synthesised calcium doped nickel ferrites $Ni_{1-x}Ca_xFe_2O_4$ (x = 0.0, 0.2, 0.4, 0.6, 0.8, 1.0) via co-precipitation method. Stoichiometric amount $FeCl_3.6H_2O$ and $NiCl_2.6H_2O$ dissolved in distilled water with constant stirring at temperature of 60°C for 30 minutes. Sodium hydroxide is used to adjust the pH of the solution 12. The resulting solution was heated at constant temperature of 85°C for 1h. The sample was dried at 100°C and calcinated at 800°C for 4h.The observed crystallite size of nanoparticle was in the range of 22-34nm. XRD, FTIR, FESEM, ICPOES and VSM techniques were used to characterize the synthesized nanoparticles.

Assar & Abosheiasha (2015) synthesised the nanocrystalline sample of ferrites $Ni_{1-x}Ca_xFe_2O_4$ (x = 0.0, 0.2, 0.4, 0.6, 0.8, 1.0) by citrate precursor method. For this $Ca(NO_3)_2.4H_2O$, $Ni(NO_3)_2.6H_2O$, $Fe(NO_3)_3.9H_2O$ and citric acid were taken as starting materials. Synthesised samples were sintered at two different temperatures 600°C and 1000°C. They found that with the increase of calcium content the thermal diffusivity of both bulk and nano sample decreased. XRD, FTIR, TEM, and VSM techniques were used to characterize the nanoparticles.

Lynda et al., (2018) synthesised spinel ferrite $Ni_yMg_{1-y}Fe_2O_4$ ($0.0 \leq y \leq 1.0$) by a sol gel combustion method. They used $Mg(NO_3)_2.6\ H_2O$, $Ni(NO_3)_2.6H_2O$ and $Fe(NO_3)_3.9H_2O$ as

starting material and urea as a fuel. The samples were synthesized by adding different concentrations of Nickel salt. The reaction mixture taken in silica crucible and treated in an air furnace at 500^{o}C for 2h @ 5^{o}C per minute. The synthesised product was washed with ethanol and dried at 700^{o}C for 1h. XRD, HRSEM, EDX, TEM, UV-Vis and VSM techniques were used to characterize the nanoparticles.

Majid et al., (2019) synthesised a series of zinc doped soft magnetic materials of $Ni_{1-x}Zn_xFe_2O_4$ (x = 0.1, 0.2, 0.3, 0.4, 0.5) by hydrothermal method. They took chloride salts of nickel, iron and zinc as starting materials. The salts of Ni and Fe were dissolved separately in deionised water and NaOH solution added drop wise with constant stirring. In the final mixture the ratio of volumes of Ni:Fe::NaOH are 1:2:8. Doping of zinc is done by decreasing the concentration of nickel chloride and increasing the concentration of zinc chloride as per requirement. The final mixture is taken in a Teflon liner container and kept in stainless steel autoclave at 220^{o}C for 16h.After a prescribed time; the contents were cooled down at room temperature. Finally the brown coloured sample was washed with deionised water and dried at 80^{o}C for overnight. XRD, FTIR, and VSM techniques were used to characterize the synthesized nanoparticles.

Shukrullah et al., (2021) synthjesized Zn doped nickel ferrite nanoparticles $Ni_{1-x}Zn_xFe_2O_4$ (x = 0.25-0.75) by co-precipitation method using $FeCl_3.6H_2O$, $NiCl_2.6H_2O$, $ZnCl_2$ and NaOH as starting materials. All the contents were taken in the stoichiometric amount and dissolved in deionised water. NaOH solution was used to adjust the pH of 12 with constant stirring for 120 minute. Now the sample is placed on preheated water bath at temperature 75^{o}C for 2h. The synthesised sample filtered and washed with water to remove the Cl^{-1} and Na^{+1} ions till the pH of the filtrate reached to 7. Now the sample dried at 70^{o}C for 4h in an electric oven. The final product grinded, cleaned with acetone and calcinated at 800^{o}C for 3h. XRD, SEM, and UV-Vis spectra techniques were used to characterize the nanoparticle.

Andhare et al.; (2020) synthesized Zn doped cobalt ferrites of $Co_{1-x}Zn_xFe_2O_4$ (x = 0.0, 0.3, 0.5, 0.5, 0.7, 1.0) via co-precipitation method using $FeCl_3.6H_2O$, $CoCl_2.6H_2O$, $ZnCl_2$ and NaOH as starting materials. To synthesize the nanoparticles the chloride salts of cobalt, zinc and iron were dissolved in water at room temperature with constant stirring for 30 min. NaOH solution was added to adjust the pH of the solution. Then the contents were heated at 80^{o}C with constant stirring for 2h. After cooling the product, it was washed with deionised water to remove sodium chloride. The synthesized sample was

centrifuged and dried at room temperature for 48h. Finally it was grinded and sintered at 900^{o}C for 4h in the furnace. TG-DTA, XRD, FTIR, VSM and UV-Vis spectra techniques were used to characterize the synthesize sample.

Iqbal et al., (2020) synthesized $MnFe_2O_4$ and Ca-$MnFe_2O_4$ nanoparticles via co-precipitation method. $FeCl_3.6H_2O$, $MnCl_2.4H_2O$, and $Ca(NO_3)_2.4H_2O$ solution of appropriate concentration were prepared in deionised water and then each preheated (95^{o}C) solution individually titrated with 3M NaOH solution of pH 9. Then the contents were stirred for 2h followed by cooling at room temperature, centrifugation, filtration and washing. The synthesized product was dried at 80^{o}C for 10h. The synthesized product was grinded to powder form and kept in a desiccators. TEM, SEM, EDX, XRD, TGA and FTIR techniques were used to characterize the nanoparticles.

Khoso et al., (2021) synthesized nickel ferrites via co-precipitation method using $FeCl_3$ and $NiCl_2$ as starting materials. Both the solutions were stirred separately at 80^{o}C for 30 min. pH of 8-9 was maintained by adding NaOH solution with constant stirring at a temperature of 70±5^{o}C for 2h. After cooling the product at room temperature, it was washed with water and ethanol, dried at 70^{o}C in an oven for 24h, grinded and calcinated at 350-550^{o}C for 3h in a muffle furnace. They used the synthesized nanoparticles for the removal of heavy metals from waste water under different parameters like concentration of synthetic waste water, pH, different dosage of adsorbents, time interval. They also studied the kinetics of the reactions. The average crystallite sine of synthesized product was found to be of 30.254nm. XRD, FE-SEM, EDX and AAS techniques were used to characterize the nanoparticle.

Patil et al., (2019) synthesized nickel ferrites by co-precipitation method. Aqueous solutions of nickel nitrate and ferric nitrate were mixed and stirred for 1h. NaOH solution was used to adjust the pH value of 7. Synthesized product was washed with water and ethanol till the pH of the filtrate reached to 7 followed by drying in an oven, grinding and calcinations in a muffle furnance at a temperature of 600^{o}C for 4h. XRD and SEM techniques were used to characterize the synthesized product.

El-Sbakhy et al., (2021) synthesized Mn doped Nickel ferrites of $Ni_{1-x}Mn_xFe_2O_4$ (x = 0.0, 0.2, 0.4, 0.6, 0.6, 0.8 and 1.0) by using flash auto-combustion method. Nitrates of nickel, manganese and iron were mixed with combustion agent urea with constant stirring at 80^{o}C for 1h. Synthesized product was sintered at 600^{o}C for 2h. XRD, FTIR, TEM, HRSEM and VSM techniques were used to characterize the synthesized nanoparticles.

3. Research Gap Identification

Many researchers have studied the effect of doping of divalent metal ions on Nickel ferrites synthesised by different methods. They also studied their electrical, magnetic, optical, structural, dielectric, electromagnetic and absorption properties. But there is very less literature available on the comparative study of Zinc, Manganese, Magnesium and Calcium doped ferrites of Nickel. Therefore in this work we have planned to study the synthesis, characterization and applications of divalent metal ion doped nickel ferrites.

4. Objectives

The main objectives of our proposed work are-

1) To synthesize Zinc, Manganese, Calcium and Magnesium doped nickel ferrite nanoparticles.

2) To characterize the synthesized magnetic nanoparticles.

3) Comparative analysis of Zinc, Manganese, Calcium and Magnesium doped nickel ferrite nanoparticles.

4) To evaluate the antimicrobial, adsorption and photo catalytic activity of magnetic nanoparticles.

5. Proposed Methodology

5.1 Chemicals Required

Chemicals required for the synthesis of MNPs will be the chloride salts of Zinc, Manganese, Calcium, Magnesium, Nickel and Iron, distilled water, Sodium hydroxide etc.

5.2 Apparatus Required

Apparatus required for the synthesis of MNPs will be magnetic stirrer, beakers, thermometer, pH meter, test tubes, measuring cylinder, silica crucible, oven, muffle furnace etc.

5.3 Experimental Procedure

Co-precipitation method will be used to synthesize the MNPs.

5.3.1 Synthesis of Nickel Ferrites

To synthesize nickel ferrites, stochiometric amount of salts of nickel chloride and ferric chloride will be mixed in distilled water with constant stirring. pH of the solution will be fixed by adding NaOH solution. Then the solution will be heated and stirred for 2-3h at

optimized temperature. Synthesis will be followed by washing, drying and grinding of the prepared sample. After that the sample will be calcinated at appropriate temperature.

5.3.2 Synthesis of Zn, Mn, Mg, and Ca doped Nickel Ferrites

To synthesize Zinc, Manganese, Magnesium and Calcium doped Nickel ferrites, stoichiometric amount of salts of Zinc chloride/Manganese Chloride/Magnesium chloride/Calcium chloride, Nickel chloride and Ferric chloride will be mixed in distilled water with constant stirring. pH of the solution will be fixed by adding NaOH solution. Then the solution will be heated and stirred for 2-3h at optimized temperature. Synthesis will be followed by washing, drying and grinding of the prepared sample. After that the sample will be calcinated at appropriate temperature.

5.4 Characterization Techniques

To characterize the synthesized magnetic nanoparticles, we will use the following characterization techniques

5.4.1 X-Rays Diffraction - XRD technique is quite helpful to elucidate the crystalline nature of the material. The diffraction pattern produced by the scattering of X-rays by the atoms of a substance gives the information regarding the arrangement of atoms in a crystal. Only the crystalline material produced significant peaks, while the amorphous materials are unable to produce any significant kind of peaks in the diffraction pattern. XRD technique is quite useful in nano and material science. This technique can measure millions of crystals and accurately determine the size distribution of nanomaterials. There are so many applications of powder XRD diffraction in science and technology like crystalline study, phase transition, size and strain broadening, forensic studies, microelectronic industry, glass industry etc. So this technique plays very important role in the growth and development of science and technology (Chauhan & Chauhan, 2014).

5.4.2 Scanning Electron Microscopy - A scanning electron microscope (SEM), create an image by scanning a surface with an electron beam. The electrons in the beam then interact with the surface and produced various signals. These signals are then used to get information about the surface topography, composition crystallography, electrical properties etc. Techniques like secondary electron imaging, qualitative and quantitative X-rays analysis, study of crystalline materials by electron channelling patterns, charge collection techniques for cathode luminescence and semiconductor samples make use of this scanning electron microscopy (Inkson, 2016).

5.4.3 Fourier Transform Infrared Spectroscopy- In this technique infrared light is used to study the chemical properties of the test sample. It is based on the principle that, a signal is generated by the interference of radiations of two beams, which is called interferogram. A molecule will absorb only if there is change in the dipole moment due to rotational and vibrational motion inside it. So this technique is quite helpful to study the vibration properties of the magnetic nanoparticles i.e. M-O (metal-oxygen) vibrations in the tetrahedral and octahedral sites (Yurdakal et al., 2019).

5.4.4 UV-Visible Spectroscopy- This technique is used to determine the absorption properties of material. When sample absorbs the electromagnetic radiations (UV visible radiations) the electrons present in it undergo excitation from ground state to excited state. The energy difference between the ground and excited state is equal to the amount of energy absorbed by the electrons. This technique is quite useful to determine optical band gap, photo catalytic activity etc. (Yurdakal et al., 2019).

5.4.5 Energy dispersive X-rays -This technique is used to identify the elemental composition of materials. The main applications of EDX are material evaluation and identification, contamination identification, spot detection analysis (regions up to 10 cm diameter), quality control screening etc. During the analysis by EDX technique the electron beam hits the inner shell of an atom ejecting an electron from that and a positively charge electron hole is created. This hole is then filled by another electron belongs to higher energy level and then characteristic X-ray is released (Mutalib et al., 2017).

5.4.6 Vibrating sample Magnetometer- This technique is used to measure the magnetic properties of the sample. It is based on Faraday's law of induction, which states that change in magnetic field will produce an electric field and measurement of this electric field gave us the information about changing magnetic field. In this technique, a magnetic sample is placed in the sample holder which lies in between the two horizontally oriented electromagnetic poles. During measurement, a fixed frequency vertical vibrations are applied on the sample, leads to change in the magnetic flux, which proportional to the magnetic moment of the sample. Change in applied magnetic field, coil position or sample position causes the change in magnetic flux. Information regarding the magnetic moment of the sample can be obtained by feeding induced voltage in lock-in-amplifier. In case of crystalline materials, the magnetic characteristics

depend upon the factors like distribution of cations in tetrahedral, octahedral sites as well as chemical composition of synthesized nanoparticles (Foner, 1996).

5.5 Applications

5.5.1 Evaluation of Antimicrobial activity

Antimicrobial activity of synthesized MNPs will be tested by well diffusion method. In this method Mueller-Hinton agar will be poured in the sterilized petri plates and allowed to solidify at room temperature. Gram-positive and Gram-negative bacterial strains will be spreaded on the agar plates. The colloidal suspension of synthesized MNPs will be loaded into the wells produced with the help of opposite side of tip. The zone of inhibition will be measured after the incubation of plates at 37^{o}C for 24 h.

5.5.2 Evaluation of adsorption activity

This activity of synthesised MNPs will be tested on waste water.

5.5.3 Evaluation of Photocatalytic activity

Photo catalytic activity of synthesized MNPs will be tested on dyes. In this evaluation mixture of dyes along with MNPs will be irradiated with light of specific wavelength. Degradation of dye will be checked by UV-Vis. spectrophotometer after regular interval of time.

6. Thesis Outline

Chapter-1 (Introduction): This chapter will include the detail about magnetic nanoparticles, nickel ferrites and doping of divalent metal ions on nickel ferrites.

Chapter-2 (Literature Review): This chapter will include the deep literature survey of nickel ferrites as well effect of doping on nickel ferrites.

Chapter-3 (Experimental and Characterisation Techniques): This chapter will give detail description about chemicals and apparatus used for the synthesis of magnetic nanoparticles. This chapter will also include the detail of various techniques used for the characterisation of magnetic nanoparticles.

Chapter-4 (Result and Discussion): This chapter will include the detail discussion on present work i.e. synthesis as well as applications of magnetic nanoparticles.

Chapter-5 (Conclusion): This chapter will comprise summary of entire study according to objectives along with conclusion.

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CERTIFICATE
(SYNOPSIS APPROVAL CERTIFICATE)

This is to certify that the Synopsis/Revised Synopsis for M.Phil. Dissertation/Ph.D. Thesis titled, "Synthesis, Characterization and Applications of Divalent metal ions doped Nicked ferrites", submitted by **Mr./Ms.** Seema Kumasi to the Career Point University, Hamirpur (H.P.), India in partial fulfillment of the requirements for the degree of **MASTER OF PHILOSOPHY/DOCTOR OF PHILOSOPHY** in the Division/Department of Chemistry, School of Basic & Applied Sciences has been approved by the Research Advisory Committee (RAC) after an Oral Examination of the student on dated 26-07-2021

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